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**Tiedtke et al.**

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(54) **MOBILE POWER SYSTEM WITH  
BIDIRECTIONAL AC-DC CONVERTER AND  
RELATED PLATFORMS AND METHODS**

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B60L 58/12; B60L 58/16; B60L 58/24;  
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(Continued)

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(57)

**ABSTRACT**

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4, 2018.

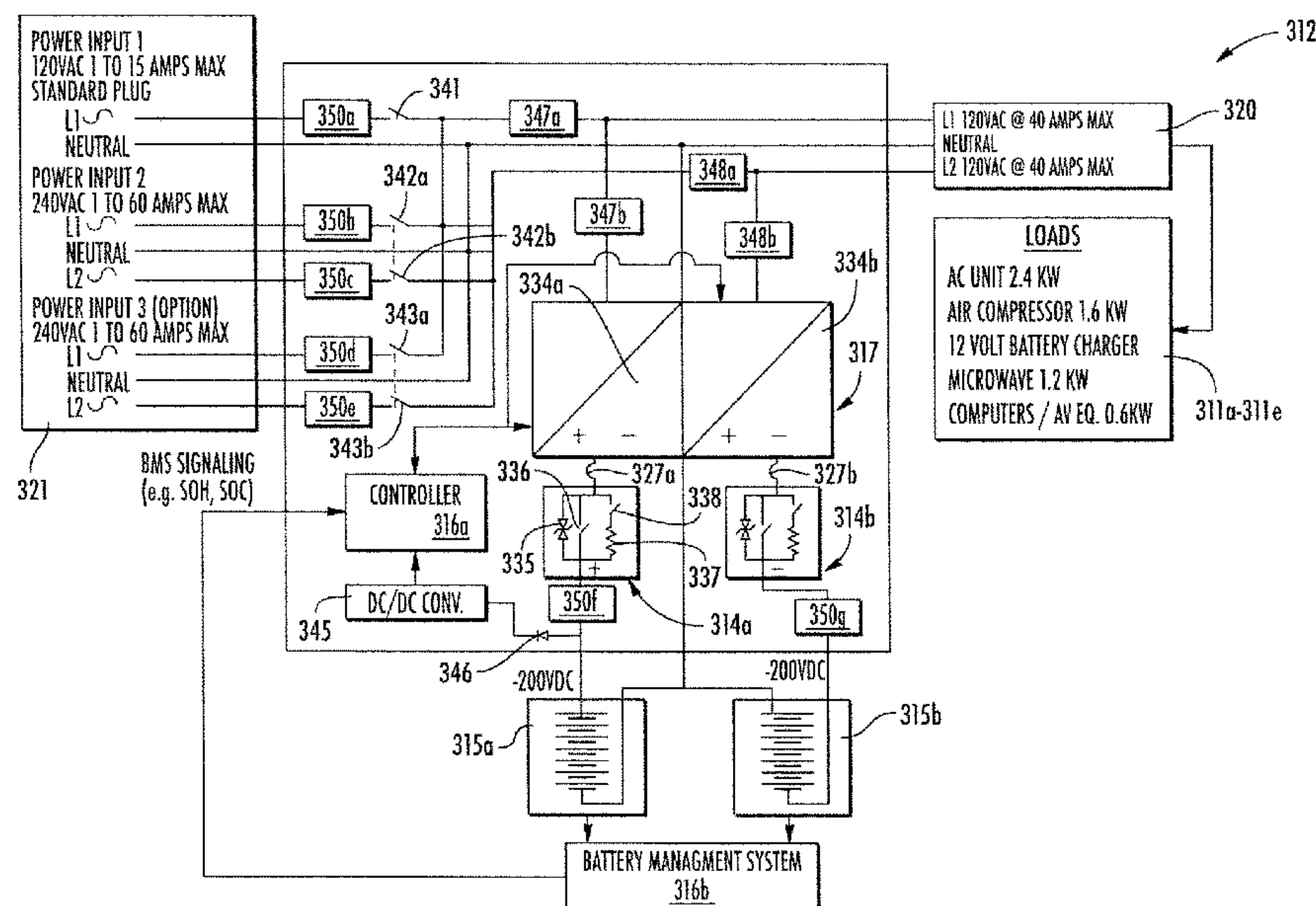
A mobile power system may include a bidirectional AC-DC  
converter configured to convert a grid AC signal to a power  
limited DC charging signal with a threshold level, a battery  
module configured to provide a DC power signal, and a  
controller coupled to the battery module and the bidirec-  
tional AC-DC converter and configured to selectively switch  
the bidirectional AC-DC converter between a first state and  
a second state. The first state may include, when a load  
power level is less than the threshold level, concurrently  
charging the battery module using the power limited DC  
charging signal and delivering the grid AC signal to a load.  
The second state may include, when the load power level is  
greater than the threshold level, concurrently converting the  
DC power signal with the bidirectional AC-DC converter  
into a battery AC signal for delivery to the load, and  
delivering the grid AC signal to the load.

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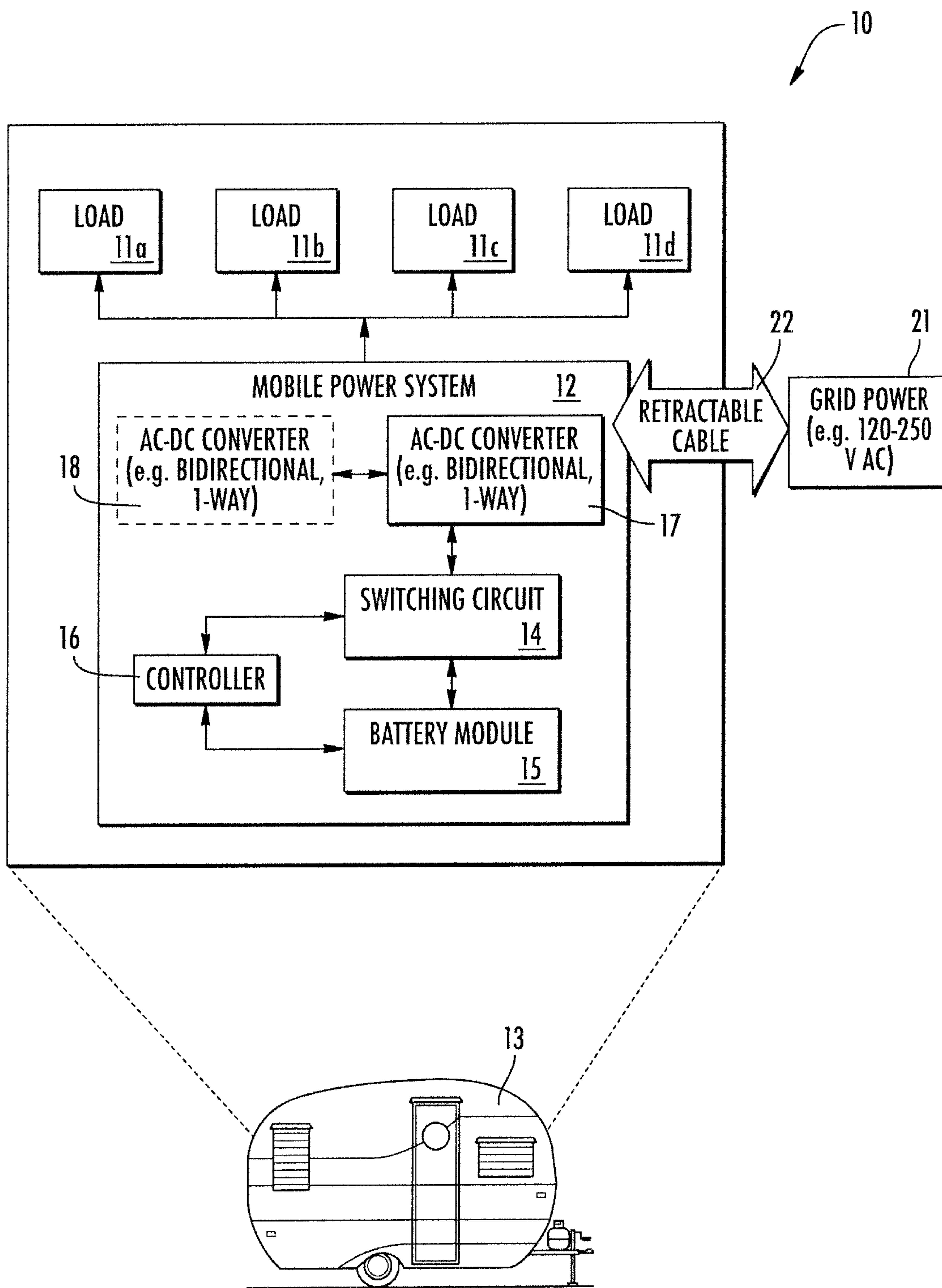


FIG. 1

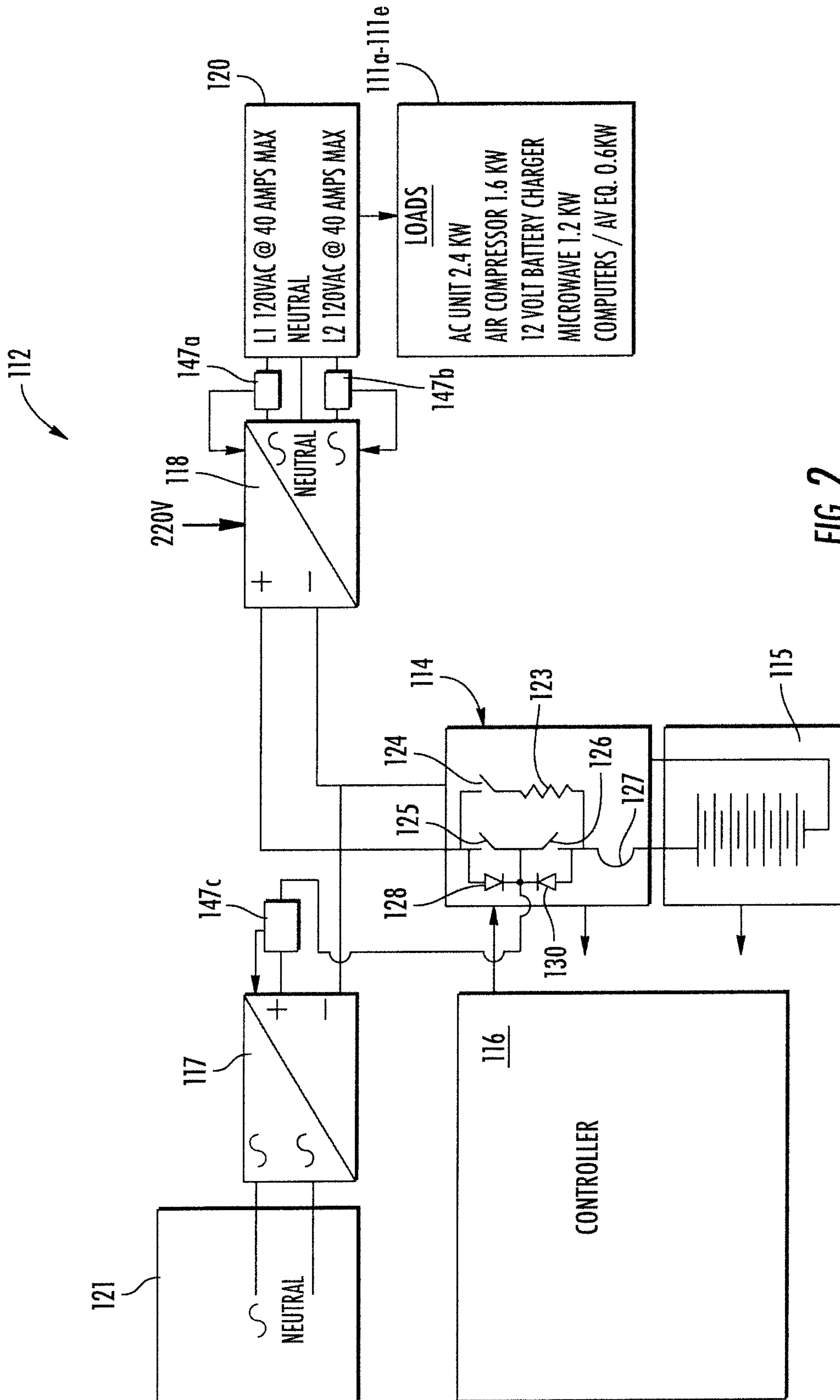


FIG. 2

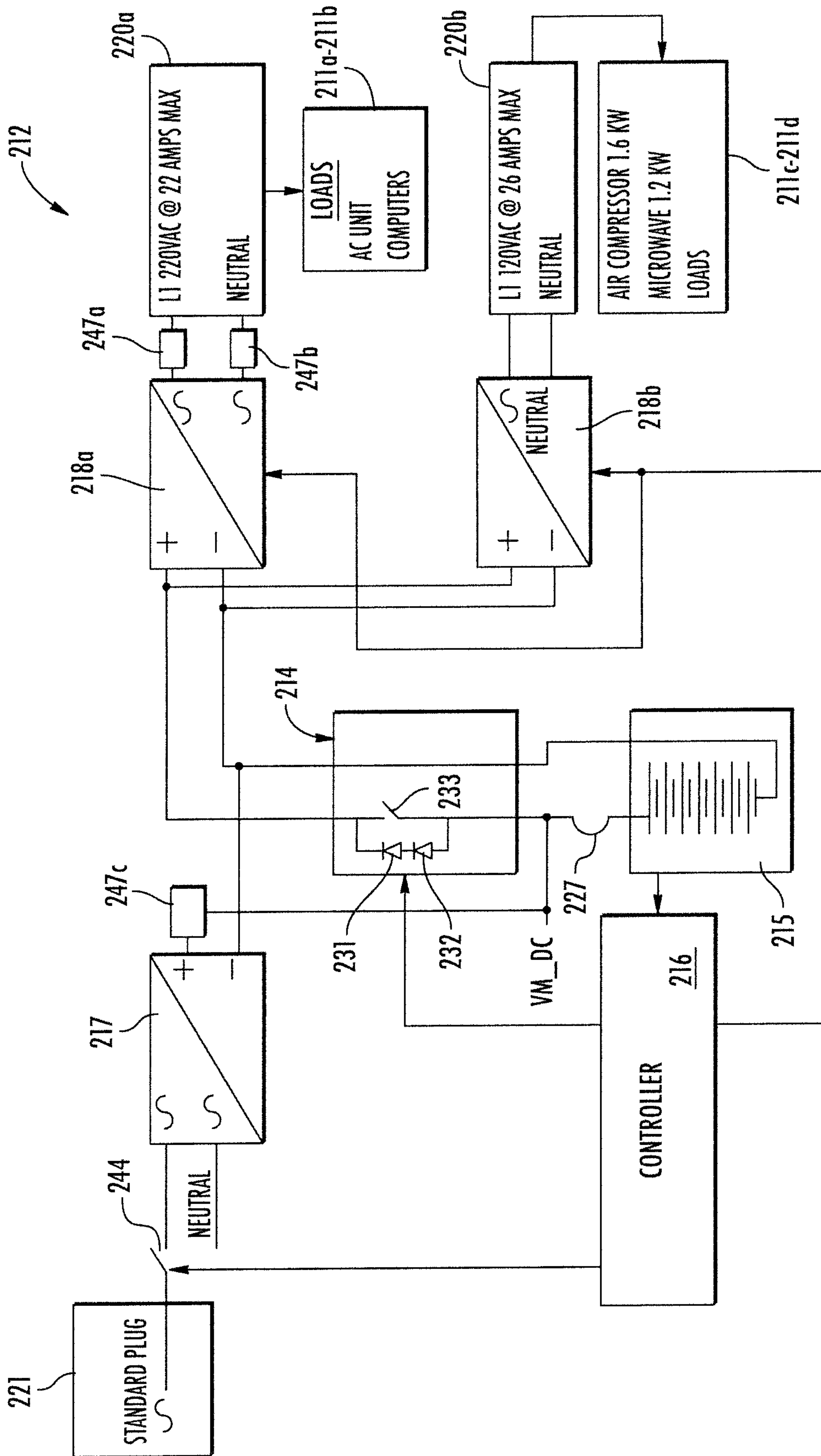


FIG. 3

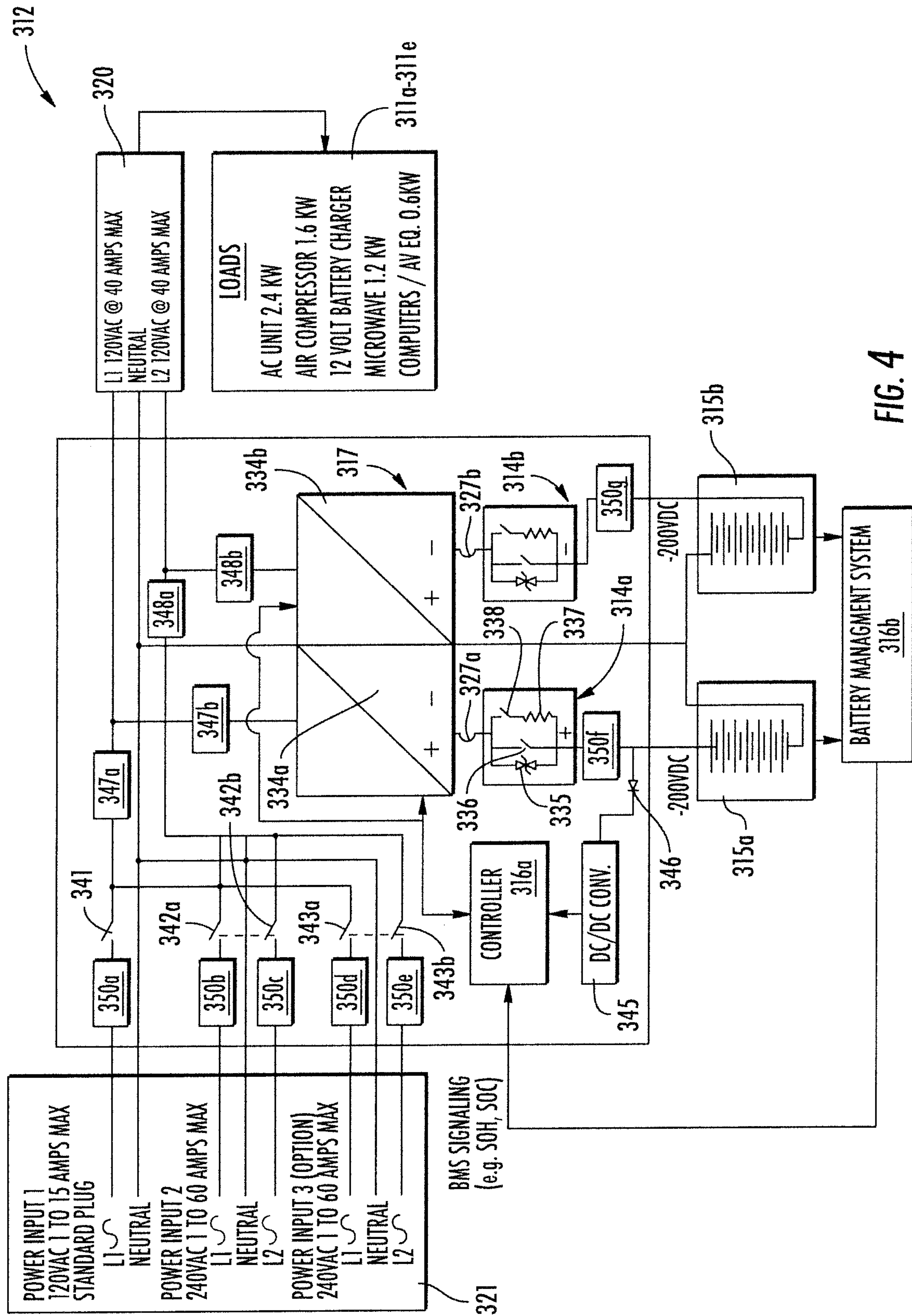


FIG. 4



**MOBILE POWER SYSTEM WITH  
BIDIRECTIONAL AC-DC CONVERTER AND  
RELATED PLATFORMS AND METHODS**

RELATED APPLICATION

This application is based upon prior filed Application No. 62/775,041 filed Dec. 4, 2018, the entire subject matter of which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

The present disclosure relates to the field of power systems, and, more particularly, to mobile vehicle power systems and related methods.

BACKGROUND

The electrical requirements for the automotive, truck, boat and recreational vehicle industry have, with few exceptions, become standardized using twelve volt direct current (DC) electrical systems and using one or more twelve volt batteries wired in parallel for storage. Most vehicles have twelve volt lights, twelve volt starter motor and twelve volt ancillary motors for, such things as windshield wipers, electric door locks and power windows. The twelve volt systems work well and twelve volt fractional horsepower motors are ideal for intermittent use as the current draw for these small motors is not great. Twelve volt engine starter motors produce very high torque for engine starting, but at a very high current draw, often in the range of 400 amps. These motors can only run for a few minutes before they drain the vehicle battery bank and/or burn up.

The twelve volt base electrical systems in vehicles have precluded the development of practical and efficient electrically driven equipment, such as air compressors, hydraulic pumps, air conditioners and vacuum systems to be mounted on service, food trucks, recreational vehicle, or over the road vehicles. Invariably, in applications where the vehicle is laden with these power demands, these devices are either powered by the onboard internal combustion engine of the vehicle or by a separate internal combustion generator.

Internal combustion approaches are effective in providing the needed energy for the application, but also come with distinct drawbacks. First and foremost, internal combustion approaches are loud and disruptive to some applications, and the engines must be constantly supplied with fuel that is inherently dangerous. Additionally, internal combustion approaches release pollution into the atmosphere and include little if any environmental controls on the exhaust. Internal combustion engines also must undergo routine maintenance to assure reliability.

In some stationary applications (e.g. food trucks), the vehicle's power demands can be supplied with grid power (i.e. shore power). In this approach, the vehicle has a cord that is plugged into a power receptacle, and the vehicle draws power from the grid. Often, the connection is 240 Volts AC, which is not always readily available.

In some approaches, the vehicle is powered by a grid power cord, a generator, and a battery pack. When the vehicle is attached to grid power, the electrical load and battery charging is handled by that source. When, as is often the case for mobile applications, there is no grid power available, the generator provides power. In these applications, the batteries, while useful, can only charge or discharge, and when in use are the sole source of power. They typically cannot be charged while they are in use. Con-

versely, while the generator and/or grid power are connected, the batteries are being charged and therefore cannot be used at all, and the user winds up being dependent on the unreliable availability of grid power or a problematic generator for any prolonged power usage.

SUMMARY

Generally, a mobile power system may include a bidirectional alternating current-direct current (AC-DC) converter configured to convert a grid AC signal to a power limited DC charging signal with a threshold level, a battery module configured to provide a DC power signal, and a controller coupled to the battery module and the bidirectional AC-DC converter and configured to selectively switch the bidirectional AC-DC converter between a first state and a second state. The first state may include, when a load power level is less than the threshold level, concurrently charging the battery module using the power limited DC charging signal and delivering the grid AC signal to a load. The second state may include, when the load power level is greater than the threshold level, concurrently converting the DC power signal with the bidirectional AC-DC converter into a battery AC signal for delivery to the load, and delivering the grid AC signal to the load.

Moreover, the controller may be configured to selectively switch the bidirectional AC-DC converter between a third state, and a fourth state. The third state may comprise, when the battery module is fully charged, and when the load power level is less than the threshold level, delivering the grid AC signal to the load and placing the bidirectional AC-DC converter in a stand-by state. The fourth state may comprise when the power limited DC charging signal is unavailable, converting the DC power signal with the bidirectional AC-DC converter into the battery AC signal for delivery to the load.

In some embodiments, the mobile power system may further comprise first and second switching circuits coupled between the battery module and the bidirectional AC-DC converter. Each of the first switching circuit and the second switching circuit may include a first switch, and a diode pair coupled in parallel to the first switch. The diode pair may comprise a pair of Zener diodes each having respective cathode terminals coupled together. Each of the first switching circuit and the second switching circuit may comprise a second switch and a resistor coupled in series. The second switch and the resistor may be coupled in parallel to the first switch. Each of the first switching circuit and the second switching circuit may comprise a current limiting element coupled between the battery module and the first switch.

Also, the load may comprise a plurality of loads, and the mobile power system may include an AC distribution circuit coupled to the bidirectional AC-DC converter and configured to deliver a plurality of AC signals respectively to the plurality of loads. The controller may comprise a battery management device configured to monitor a plurality of parameters related to the battery module. The plurality of parameters may comprise a total voltage value, voltage values of individual battery cells, a temperature value, a state of charge (SOC) value, a state of health (SOH) value, and a current value.

Another aspect is directed to a mobile vehicle platform comprising a vehicle body, a plurality of loads carried by the vehicle body, and a mobile power system carried by the vehicle body and powering the plurality of loads. The mobile power system may include a bidirectional AC-DC converter configured to convert a grid AC signal to a power



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limited DC charging signal with a threshold level, a battery module configured to provide a DC power signal, and a controller coupled to the battery module and the bidirectional AC-DC converter and configured to selectively switch the bidirectional AC-DC converter between a first state and a second state. The first state may include, when a load power level is less than the threshold level, concurrently charging the battery module using the power limited DC charging signal and delivering the grid AC signal to the plurality of loads. The second state may comprise, when the load power level is greater than the threshold level, concurrently converting the DC power signal with the bidirectional AC-DC converter into a battery AC signal for delivery to the plurality of loads, and delivering the grid AC signal to the plurality of loads.

Yet another aspect is directed to a method for making a mobile power system. The method may include coupling a bidirectional AC-DC converter configured to convert a grid AC signal to a power limited DC charging signal with a threshold level, coupling a battery module configured to provide a DC power signal, and coupling a controller to the battery module and the bidirectional AC-DC converter and configured to selectively switch the bidirectional AC-DC converter between a first state and a second state. The first state may include, when a load power level is less than the threshold level, concurrently charging the battery module using the power limited DC charging signal and delivering the grid AC signal to the plurality of loads. The second state may comprise, when the load power level is greater than the threshold level, concurrently converting the DC power signal with the bidirectional AC-DC converter into a battery AC signal for delivery to the plurality of loads, and delivering the grid AC signal to the plurality of loads.

#### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic diagram of a mobile vehicle platform, according to the present disclosure.

FIG. 2 is a schematic diagram of a mobile power system, according to a first embodiment the present disclosure.

FIG. 3 is a schematic diagram of a mobile power system, according to a second embodiment the present disclosure.

FIG. 4 is a schematic diagram of a mobile power system, according to a third embodiment the present disclosure.

#### DETAILED DESCRIPTION

The present disclosure will now be described more fully hereinafter with reference to the accompanying drawings, in which several embodiments of the invention are shown. This present disclosure may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the present disclosure to those skilled in the art. Like numbers refer to like elements throughout, and base 100 reference numerals are used to indicate similar elements in alternative embodiments.

Referring initially to FIG. 1, a mobile vehicle platform 10 according to the present disclosure is now described. The mobile vehicle platform 10 illustratively includes a vehicle body 13, and a mobile power system 12 carried by the vehicle body. In the illustrated embodiment, the vehicle body 13 is a recreational vehicle. Of course, in other

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embodiments, the vehicle body 13 may comprise a trailer, a food truck vehicle, or a mobile entertainment vehicle, such as a mobile escape room.

The mobile vehicle platform 10 illustratively includes a plurality of loads 11a-11d carried by the vehicle body 13 and powered by the mobile power system 12. For example, the plurality of loads 11a-11d may comprise an air compressor, lighting devices, 12 Volt lighting, games, hydraulic pumps, video screens, air conditioning units, and computing equipment.

The mobile power system 12 illustratively includes one or more AC-DC converters 17-18 (second converter is optional and indicated with dashed lines), a grid power connection 21, and a retractable cable 22 coupled between the one or more AC-DC converters and the grid power connection. The mobile power system 12 illustratively includes a switching circuit 14 coupled to the one or more AC-DC converters 17-18, a battery module 15 coupled to the switching circuit, and a controller 16 coupled to the switching circuit and the battery module.

In some embodiments, the battery module 15 may comprise a bank of Lithium Ion battery cells. Each of the one or more AC-DC converters 17-18 may comprise one or more of an AC to DC converter, a DC to AC converter, or a bidirectional AC-DC converter.

The controller 16 is configured to cooperate with the switching circuit 14 to control the flow of current into and from the battery module 15. Advantageously, the switching circuit 14 may enable the battery module 15 to both be charged and provide power for the mobile vehicle platform 10. It should be appreciated that the mobile vehicle platform 10 shown in FIG. 1 is an illustrative example, and the mobile vehicle platform may comprise the mobile power system embodiments 112, 212, 312 (See FIGS. 2-4) disclosed herein.

Although not shown, the mobile power system 12 may comprise a command interface coupled to the controller 16. The command interface may include a plurality of command functions for the user to control operation of the mobile power system 12. Also, the command interface may include a status dashboard providing the current operating state of the mobile power system 12. For example, the command interface may comprise a Raspberry Pi microcontroller, as available from the Raspberry Pi Foundation of Cambridge, United Kingdom. Also, in some embodiments, the command interface may be accessible via a local wireless area network (WLAN) connection. Indeed, in some embodiments, the user may use an associated mobile wireless communications device to monitor and/or control the command interface mobile power system 12.

Referring now additionally to FIG. 2, another embodiment of the mobile power system 112 is now described. In this embodiment of the mobile power system 112, those elements already discussed above with respect to FIG. 1 are incremented by 100 and most require no further discussion herein. This embodiment differs from the previous embodiment in that this mobile power system 112 illustratively includes an AC-DC converter 117 configured to convert a grid AC signal to a power limited DC charging signal, and a DC-AC converter 118 coupled to the AC-DC converter. In this embodiment, the grid power connection 121 illustratively includes a standard 120 Volt AC plug (e.g. power limited to 13 Amp maximum).

The mobile power system 112 illustratively includes a battery module 115 configured to provide a DC power signal, and a switching circuit 114 coupled between the battery module, and the AC-DC converter 117 and the



DC-AC converter **118**. The switching circuit **114** illustratively includes a first switch **125**, and a first diode **128** coupled in parallel to the first switch.

It should be noted that the first diode **128** is optional. In embodiments that include the first diode **128**, the DC-AC converter **118** may comprise a two-way converter (i.e. it can convert AC to DC additionally), and is coupled to a 220 Volt AC input.

Moreover, the switching circuit **114** illustratively includes a second diode **130** coupled to the first diode **128**, a second switch **126** coupled in parallel to the second diode, and a third switch **124** and a resistor **123** coupled in series. The third switch **124** and the resistor **123** are illustratively coupled in parallel to the first switch **125** and the second switch **126**. The switching circuit **114** illustratively includes a current limiting element **127** (e.g. 150 Amp fuse/circuit breaker) coupled between the battery module **115** and the second switch **126**. Also, the first diode **128** and the second diode **130** have respective cathode terminals coupled together, and also coupled between the first switch **125** and the second switch **126**.

The mobile power system **112** illustratively includes a controller **116** coupled to the battery module **115** and the switching circuit **114**. The controller **116** is configured to selectively switch the switching circuit **114** between a first state, a second state, and a third state based upon a threshold voltage value from the battery module. The first state comprises alternatively one of concurrently charging the battery module **115** using the power limited DC charging signal and routes the DC power signal to the DC-AC converter **118**, or providing the DC power signal using the battery module **115** without the power limited DC charging signal, i.e. when grid power is unavailable. In other words, the first state is normal operation, and in the first state, the first, second, and third switches **124-126** are all closed.

The second state relates to a battery under voltage condition (i.e. one or more of the voltage values of individual battery cells or the total voltage value is less than the minimum threshold voltage value). Here, the second state comprises charging the battery module **115** using the power limited DC charging signal and blocking the DC power signal to the DC-AC converter. In other words, the battery module **115** is charged only, and there is no discharge. In particular, the controller **116** is configured to open the first switch **125** in the second state then after 50 mS open the third switch **124**. Switching in this manner limits the maximum current and voltage that the opening switch will be exposed to. Thus extending the life of the switch. When sufficient charge has been delivered to the battery module **115** switch **124** closes then after 2 seconds switch **125** closes returning to the first state.

The third state relates to a battery overvoltage condition (i.e. one or more of the voltage values of individual battery cells or the total voltage value is greater than the maximum threshold voltage value). The third state comprises blocking charging of the battery module **115** and routing the DC power signal to the DC-AC converter **118**. In other words, the battery module **115** is discharged only, and there is no charging. In particular, the controller **116** is configured to open the second and third switch **126** and **124** in the third state, and **125** switch remain closed.

In the illustrated embodiment, the mobile power system **112** further comprises an AC distribution circuit **120** coupled to the DC-AC converter **118** and configured to deliver a plurality of AC signals respectively to a plurality of loads **111a-111e**. The plurality of loads **111a-111e** may have a cumulative power rating greater than 4.8 kW.

In the illustrated embodiment, the controller **116** comprises a battery management device configured to monitor a plurality of parameters related to the battery module **115**. For example, the plurality of parameters may comprise a total voltage value, voltage values of individual battery cells (i.e. are in normal operating range), a temperature value, a SOC value, a SOH value, and a current value. The grid AC signal may comprise a 100-250 Volt AC signal, and the DC power signal may comprise a 40-59 Volt DC signal. The controller **116** also includes logic circuitry to control the state of the first, second, and third switches **124-126**.

In the illustrated embodiment, the mobile power system **112** further comprises of a current monitor **147c** configured to monitor current draw from the grid power connection **121**, thereby preventing tripping a load protection element within the grid power connection (i.e. a circuit breaker). The plurality of current monitors **147a-147b** is configured to monitor a current load going into the AC distribution circuit **120**. Each of the plurality of current monitors **147a-147c** comprises an active current monitor providing instant feedback to prevent excessive current draw.

Yet another aspect is directed to a method for making a mobile power system **112**. The method includes coupling an AC-DC converter **117** configured to convert a grid AC signal to a power limited DC charging signal, and coupling a DC-AC converter **118** to the AC-DC converter. The method includes coupling a switching circuit **114** between a battery module **115**, and the AC-DC converter **117** and the DC-AC converter **118**. The battery module **115** configured to provide a DC power signal. The switching circuit **114** includes a first switch **125**, and a first diode **128** coupled in parallel to the first switch. The method also comprises coupling a controller **116** to the battery module **115** and the switching circuit **114**. The controller **116** is configured to selectively switch the switching circuit **114** between a first state and a second state. The first state concurrently charges the battery module **115** using the power limited DC charging signal and routes the DC power signal to the DC-AC converter **118**, and the second state provides the DC power signal using the battery module without the power limited DC charging signal.

Advantageously, the mobile power system **112** permits the battery module **115** to handle all peak loads while a 120 v variable amperage charger-transformer **121** sends a stream of constant current back into the system, supplementing the battery's usage. In an example embodiment/implementation of the mobile power system **112**, over the course of a 6, 8, 10 hour work day, the charger increased the life of the battery module **115** by between 50-100%, depending largely on the air conditioning compressor's load.

Referring now additionally to FIG. 3, another embodiment of the mobile power system **212** is now described. In this embodiment of the mobile power system **212**, those elements already discussed above with respect to FIGS. 1-2 are incremented by 200 and most require no further discussion herein. This embodiment differs from the previous embodiment in that this mobile power system **212** illustratively includes an AC-DC converter **217** configured to convert a grid AC signal to a power limited DC charging signal, and first and second DC-AC converters **218a-218b** coupled to the AC-DC converter.

The mobile power system **212** illustratively includes a battery module **215** configured to provide a DC power signal, and a switching circuit **214** coupled between the battery module, and the AC-DC converter **217** and the first and second DC-AC converters **218a-218b**. In this embodi-



ment, the grid power connection **221** illustratively includes a standard 120 Volt AC plug (e.g. power limited to 13 Amp maximum or 1560 watts).

The mobile power system **212** illustratively includes a controller **216** coupled to the battery module **215**, the switching circuit **214**, and the first and second DC-AC converters **218a-218b**. The controller **216** is configured to selectively switch the switching circuit **214** between a first state, a second state, a third state, and a fourth state. The first state includes one of concurrently charging the battery module **215** using the power limited DC charging signal and routing the DC power signal to the first and second DC-AC converters **218a-218b**, or providing the DC power signal using the battery module **215** without the power limited DC charging signal, i.e. when grid power is unavailable. In other words, the first state relates to normal operation.

The switching circuit **214** illustratively includes a switch **233**, a first diode **231**, and a second diode **232**. The first diode **231** and the second diode **232** are coupled in parallel to the switch **233**. Additionally, the switching circuit **214** includes a current limiting element (e.g. 500 Amp fuse/circuit breaker) coupled between the battery module **215** and the second diode **232**. The first diode **231** illustratively includes an anode terminal coupled to a cathode terminal of the second diode **232**, i.e. they are coupled in series.

In the illustrated embodiment, the first DC-AC converter **218a** is configured to generate a first AC power signal, and the second DC-AC converter **218b** is configured to generate a second AC power signal. Here, the second AC power signal (e.g. 120 Volt AC) has a voltage level less than that of the first AC power signal (e.g. 220 Volt AC). The mobile power system **212** illustratively includes first and second AC distribution circuits **222a-220b** respectively coupled to the first DC-AC converter and the second DC-AC converter **218a-218b**.

Each of the first and second AC distribution circuits **220a-220b** is configured to deliver a plurality of AC signals respectively to a plurality of loads **211a-211b** & **211c-211d**. For example, the plurality of loads **211a-211b** & **211c-211d** may have a cumulative power rating greater than 4.8 kW.

Also, in this embodiment, similar to the embodiment of FIG. 2, the controller **216** includes a battery management device configured to monitor a plurality of parameters related to the battery module. Also, the grid AC signal may include a 100-250 Volt AC signal, and the DC power signal may comprise a 12-17 Volt DC signal.

Also, the mobile power system **212** illustratively includes a cutoff switch **244** coupled to the controller **216**. Depending on the values of the plurality of parameters (i.e. if a cell voltage is over the maximum threshold limit.), the controller **216** may disconnect the grid AC signal. In other words, the controller **216** can island the mobile power system **212** if needed for safety.

The second state relates to a battery under voltage condition (i.e. one or more of the voltage values of individual battery cells or the total voltage value is less than the minimum threshold voltage value). Here, the second state comprises charging the battery module **215** using the power limited DC charging signal and disabling the first DC-AC converter and the second DC-AC converter **218a-218b**. In particular, the controller **216** is configured to disable the first DC-AC converter and the second DC-AC converter **218a-218b** so that the battery module **215** is recharged without any power draw to the plurality of loads **211a-211b** & **211c-211d**.

The third state relates to a battery overvoltage condition (i.e. one or more of the voltage values of individual battery

cells or the total voltage value is greater than the maximum threshold voltage value). The third state comprises comprising blocking charging of the battery module **215** and routing the DC power signal to the first DC-AC converter and the second DC-AC converter **218a-218b**. In other words, due to the current health state of the individual batteries in the battery module **215**, the charge current into the battery module must be stopped. Here, the controller **216** is configured to open the cut-off switch **244**, which isolates the mobile power system **212** from the grid power connection **221**.

The fourth state relates to a supply over voltage for the first DC-AC converter and the second DC-AC converter **218a-218b**. In particular, the first DC-AC converter and the second DC-AC converter **218a-218b** each have a desired input DC voltage range. In some applications, particularly when the battery module **215** is fully charged and the cells have their highest charged voltage, the DC power signal outputted to the first DC-AC converter and the second DC-AC converter **218a-218b** is greater than a desired range, and damage can result. In this state, the controller **216** is configured to cause the switch **233** to open. This prevents the battery module **215** from providing an over voltage condition to the DC-AC converters **218a-218b** a voltage drop in the DC power signal is provided (via the first and second diodes **231**, **232**).

Yet another aspect is directed to a method for making a mobile power system **212**. The method comprises coupling an AC-DC converter **217** configured to convert a grid AC signal to a power limited DC charging signal, coupling first and second DC-AC converters **218a-218b** to the AC-DC converter, and coupling a battery module **215** configured to provide a DC power signal. The method further comprises coupling a switching circuit **214** between the battery module **215**, and the AC-DC converter **217** and the first and second DC-AC converters **218a-218b**. The switching circuit **214** includes a switch **233**, a first diode **231**, and a second diode **232** coupled in parallel to the switch. The method includes coupling a controller **216** to the battery module **215**, the switching circuit **214**, and the first and second DC-AC converters **218a-218b**. The controller **216** is configured to selectively switch the switching circuit **214** between a first state and a second state. The first state includes concurrently charging the battery module **215** using the power limited DC charging signal and routing the DC power signal to the first and second DC-AC converters **218a-218b**, and the second state provides the DC power signal using the battery module **215** without the power limited DC charging signal. Advantageously, this embodiment may be less expensive to manufacture, and has reduced size, and weight however it is the least effect of embodiments due to 100% of the power goes through the AC-DC converter **217** and the DC-AC converters **218a-218b** plus when the battery is charged more loss is incurred from the voltage dropping diodes **231-232**.

Referring now additionally to FIG. 4, another embodiment of the mobile power system **312** is now described. In this embodiment of the mobile power system **312**, those elements already discussed above with respect to FIGS. 1-3 are incremented by 300 and most require no further discussion herein. This embodiment differs from the previous embodiment in that this mobile power system **312** illustratively includes a bidirectional AC-DC converter **317** configured to convert a grid AC signal to a power limited DC charging signal with a threshold level (e.g. limited by a circuit breaker associated with the grid AC signal, such as a 15 amp maximum being the threshold level), and a battery



module configured to provide a DC power signal. In this embodiment, the battery module comprises first and second battery modules **315a-315b**.

The mobile power system **312** illustratively includes first and second switching circuits **314a-314b** coupled between the first and second battery modules **315a-315b** and the bidirectional AC-DC converter **317**. The mobile power system **312** illustratively includes a controller **316a-316b** coupled to the first and second battery modules **315a-315b** and the first and second switching circuits **314a-314b**.

The controller **316a-316b** is configured to selectively switch the bidirectional AC-DC converter **317** between a first state, a second state, a third state, and a fourth state. The first state includes, when a load power level is less than the threshold level, concurrently charging the first and second battery modules **315a-315b** using the power limited DC charging signal and delivering the grid AC signal to a plurality of loads **311a-311e**. The second state includes, when the load power level is greater than the threshold level, concurrently converting the DC power signal with the bidirectional AC-DC converter **317** into a battery AC signal for delivery to the plurality of loads **311a-311e**, and delivering the grid AC signal to the plurality of loads. The third state comprises, when the first and second battery modules **315a-315b** are fully charged, and when the load power level is less than the threshold level, delivering the grid AC signal to the plurality of loads **311a-311e** and placing the bidirectional AC-DC converter **317** in a stand-by state. The fourth state comprises when the power limited DC charging signal is unavailable, converting the DC power signal with the bidirectional AC-DC converter **317** into the battery AC signal for delivery to the plurality of loads **311a-311e**.

Each of the first switching circuit **314a** and the second switching circuit **314b** illustratively includes a first switch **336**, and a diode pair **335** coupled in parallel to the first switch. Each diode of the diode pair **335** comprises a Zener diode, each having respective cathode terminals coupled together. As will be appreciated, the diode pair **335** is coupled as a waveform clipping device. Also, it should be appreciated that the diode pair **335** may be omitted in some embodiments.

More specifically, each of the first switching circuit **314a** and the second switching circuit **314b** comprises a second switch **338** and a resistor **337** coupled in series, and the second switch and the resistor are coupled in parallel to the first switch **336**. Each of the first switching circuit **314a** and the second switching circuit **314b** illustratively includes a current limiting element **327a-327b** (e.g. a 30 Amp fuse/circuit breaker) coupled between the first and second battery modules **315a-315b** and the first switch **336**.

The mobile power system **312** illustratively includes an AC distribution circuit **320** coupled to the bidirectional AC-DC converter **317** and configured to deliver a plurality of AC signals respectively to the plurality of loads **311a-311e**. The plurality of loads **311a-311e** may have a cumulative power rating greater than 9.6 kW.

Also, as in the embodiments of FIGS. 2-3, the controller **316a-316b** includes a battery management device **316b** configured to monitor a plurality of parameters related to the first and second battery modules **315a-315b**. In the illustrated embodiment, the first and second battery modules **315a-315b** may provide a total power storage of 10-16 kWh. In this embodiment, the controller **316a** and the battery management device **316b** are depicted as separate circuits, but in other embodiments, the circuits may be integrated. The grid AC signal may include a 100-250 Volt AC signal,

and the DC power signal may comprise a +/-170-227 Volt DC signal, i.e. 314-454 in total.

In this embodiment, the grid power connection **321** illustratively includes a plurality of power inputs providing a corresponding plurality of grid AC signals. Here, the plurality of grid AC signals comprise first and second 240 Volt AC signals (1-50 Amps), and a 120 Volt AC grid AC signal (1-13 Amps). In some embodiments, one or more of the plurality of grid AC signals can be omitted for power source simplification.

The bidirectional AC-DC converter **317** illustratively includes first and second power blocks **334a-334b**. The first and second power blocks **334a-334b** are independent power blocks. The first power block **334a** is selectively coupled to one or more of the first and second 240 Volt AC signals, and the 120 Volt AC grid AC signal. The second power block **334b** is selectively coupled to one or more of the first and second 240 Volt AC signals. Because of the independence of the first and second power blocks **334a-334b**, the mobile power system **312** can utilize multiple grid power standards with varying phases and voltages simultaneously.

Also, the mobile power system **312** illustratively includes a plurality of input cutoff switches **341, 342a-342b, 343a-343b** for each grid AC signal. If operational or safety concerns necessitate opening of these cutoff switches **341, 342a-342b, 343a-343b**, the controller **316a-316b** can deactivate (i.e. place in an open state) any one or more of the cutoff switches.

In the off state, the controller **316a-316b** is configured to cause the first switch **336**, the second switch **338**, and the plurality of input cutoff switches **341, 342a-342b, 343a-343b** are all set to an open state. When the mobile power system **312** is powered up, the controller **316a-316b** is configured to review the DC supplies available, if the DC supply is in the proper voltage range the second switch **338** is closed, then after a delay, the first switch **336** is closed and the second switch is opened. This method limits the DC inrush current. Once the first switch **336** is closed, the controller **316a-316b** is configured to review the AC supplies available (both voltages and the phases) from the grid power connection **321** and selectively control the plurality of input cutoff switches **341, 342a-342b, 343a-343b** to provide the most efficient power source.

Helpfully, the mobile power system **312** includes safeguards for safety, which will shut down once certain parameters are reached. In the event that grid AC power is turned off, the grid AC power is disconnected so that power cannot be sent out through the charging cord, and the first and second battery modules **315a-315b** will simply discharge until they reach a minimum power level limit, shut off, and wait to be charged again. In the event of a power outage, when the input source stops supplying and starts demanding a load (e.g. when a local transformer fails in a storm), the bidirectional AC-DC converter **317** instantaneously shuts down the system, disconnects the AC source so power cannot be sent out through the charging cord, and then brings the system back up. This is all accomplished within 50 milliseconds, allowing for all systems on the mobile vehicle platform to stay powered on and functional. Also, there is surge protection built into the bidirectional AC-DC converter **317**.

Also, the mobile power system **312** illustratively includes a DC-DC converter **345**, and a diode **346** coupled to the DC-DC converter. The DC-DC converter **345** comprises a step-down converter, which can provide a lower voltage



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power source for the controller. The diode **346** is coupled between the first switching circuit **314a** and the first battery module **315a**.

Yet another aspect is directed to a method for making a mobile power system **312**. The method comprises coupling a bidirectional AC-DC converter **317** configured to convert a grid AC signal to a DC power limited charging signal, coupling a battery module **315a-315b** configured to provide a DC power signal, and coupling a controller **316a-316b** to the battery module and the bidirectional AC-DC converter and configured to selectively switch the bidirectional AC-DC converter between a first state and a second state. The first state may include, when a load power level is less than the threshold level, concurrently charging the battery module **315a-315b** using the power limited DC charging signal and delivering the grid AC signal to the plurality of loads **311a-311e**. The second state may comprise, when the load power level is greater than the threshold level, concurrently converting the DC power signal with the bidirectional AC-DC converter **317** into a battery AC signal for delivery to the plurality of loads **311a-311e**, and delivering the grid AC signal to the plurality of loads.

In any of the mobile power system embodiments **112**, **212**, **312** noted herein, one or more of the described components may be carried on one or more circuit boards. Indeed, in some advantageous embodiments, the mobile power system could comprise a single circuit board with various integrated circuit components thereon.

In these circuit board embodiments, due to the high current nature of mobile power applications, current may need to be routed off chip or off the board, and not via conductive traces on the circuit board. In these applications, the one or more circuit board include openings adjacent active components on the circuit boards, and the mobile power system would include a plurality of bus bars (e.g. copper bus bar) extending under the circuit board. Each bus bar would include one or more connection posts to extend through the openings for connection to the active components on the circuit board (e.g. soldering).

Advantageously, the mobile power system **312** is substantially more efficient than existing approaches for power conversion. Indeed, this embodiment is more efficient than the embodiments depicted in FIGS. 2-3. This is due to the elimination of the multiple AC-DC converters, step-down transformers, and rectifiers. The bidirectional AC-DC converter **317** directs grid AC power without interruption into the mobile vehicle platform, while the first and second battery modules **315a-315b** handle all loads in excess of the grid AC power limit.

The mobile power system **312** illustratively includes a plurality of current monitors **347a-347b**, **348a-348b**, and a plurality of voltage monitors **350a-350g**. Each of the plurality of current monitors **347a-347b**, **348a-348b** passes a current value to the controller **316a-316b**. Each of the plurality of voltage monitors **350a-350g** passes a voltage value to the controller **316a-316b**.

In some embodiments, additional voltage monitors are located adjacent the current monitors **347b**, **348b**, and the current limiting elements **327a-327b**. The controller **316a-316b** uses these current/voltage values to monitor the real-time load demands and to efficiently route energy in accordance with a plurality of operational states. The plurality of operational states comprises:

1. directing energy from the grid power connection **321** to a balanced combination of the plurality of loads **311a-**

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**311e** and the first and second battery modules **315a-315b** (load demands are less than maximum grid power; the first state);

2. directing energy from the grid power connection **321** to only the plurality of loads **311a-311e** and directing energy concurrently from the first and second battery modules **315a-315b** to the plurality of loads **311a-311e** (load demands are greater than maximum grid power; combined power mode, second state).
3. directing energy from the grid power connection **321** only to the plurality of loads **311a-311e**, and placing the bidirectional AC-DC converter **317** into a stand-by mode (load demands meet maximum grid power; or when the first and second battery modules **315a-315b** are fully charged and load demands are less than or equal to maximum grid power);
4. grid power connection **321** not available or indicates an error/problem state, energy from the first and second battery modules **315a-315b** is directed to the plurality of loads **311a-311e**, and the bidirectional AC-DC converter **317** is disconnected from the grid power connection (battery power only mode; fourth state).
5. directing energy from the grid power connection **321** only to the first and second battery modules **315a-315b** (load demands are near zero; charging mode, e.g. under voltage condition);
6. when the bidirectional AC-DC converter **317** or the first and second battery modules **315a-315b** generate an error message, directing energy from the grid power connection **321** only to the plurality of loads **311a-311e** and electrically floating the bidirectional AC-DC converter and the first and second battery modules (bypass mode, error state); and
7. the controller **316a-316b** causes the first switch **336**, the second switch **338**, and the plurality of input cutoff switches **341**, **342a-342b**, **343a-343b** are all set to an open state (off state).

If the mobile vehicle platform power load drops below that a limit, power is diverted into the first and second battery modules **315a-315b** for recharging. If the first and second battery modules **315a-315b** are full, then the load requested of the shore power is below its limit. In efficient fashion, the bidirectional AC-DC converter **317**, in real time, directs or balances the energy from the grid AC signal into the first and second battery modules **315a-315b** for charging and into the AC distribution circuit **320** for driving the needed plurality of loads **311a-311e**.

The mobile power system **312** may achieve an approximate 97% energy efficiency when converting voltages AC-DC or DC-AC. Also, since only a fractional amount of the total energy is put through conversion, further efficiency is achieved. This gain in conversion efficiency directly correlates to a gain in battery life and grid AC efficiency. Additionally, it simultaneously reduces the heat load, which in turn reduces the energy demand from the air conditioning compressor needed maintain a comfortable temperature. These represent significant energy savings. Finally, the mobile power system **312** is exceptionally small, reducing the cubic footprint and weight.

Other features relating to mobile power systems are disclosed in applications: titled "MOBILE POWER SYSTEM WITH MULTIPLE CONVERTERS AND RELATED PLATFORMS AND METHODS," application Ser. No. 16/701,456; and titled "MOBILE POWER SYSTEM WITH MULTIPLE DC-AC CONVERTERS AND RELATED PLATFORMS AND METHODS," U.S. Pat. No. 11,070,073, all incorporated herein by reference in their entirety.



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Many modifications and other embodiments of the present disclosure will come to the mind of one skilled in the art having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Therefore, it is understood that the present disclosure is not to be limited to the specific embodiments disclosed, and that modifications and embodiments are intended to be included within the scope of the appended claims.

That which is claimed is:

1. A mobile power system comprising:
  - a bidirectional alternating current-direct current (AC-DC) converter configured to convert a grid AC signal to a power limited DC charging signal with a threshold level;
  - a battery module configured to provide a DC power signal;
  - a controller coupled to said battery module and said bidirectional AC-DC converter and configured to selectively switch said bidirectional AC-DC converter between a first state and a second state; and
  - at least one switching circuit coupled between said battery module and said bidirectional AC-DC converter and comprising
    - a first switch, and
    - a diode pair coupled in parallel to said first switch, each diode of said diode pair having respective cathode terminals coupled together;
  - the first state comprising, when a load power level is less than the threshold level, concurrently charging said battery module using the power limited DC charging signal and delivering the grid AC signal to a load;
  - the second state comprising, when the load power level is greater than the threshold level, concurrently converting the DC power signal with said bidirectional AC-DC converter into a battery AC signal for delivery to the load, and delivering the grid AC signal to the load.
2. The mobile power system of claim 1 wherein said controller is configured to selectively switch said bidirectional AC-DC converter between a third state, and a fourth state; wherein the third state comprises, when said battery module is fully charged, and when the load power level is less than the threshold level, delivering the grid AC signal to the load and placing said bidirectional AC-DC converter in a stand-by state; and wherein the fourth state comprises when the power limited DC charging signal is unavailable, converting the DC power signal with said bidirectional AC-DC converter into the battery AC signal for delivery to the load.
3. The mobile power system of claim 1 wherein said at least one switching circuit comprises first and second switching circuits coupled between said battery module and said bidirectional AC-DC converter.
4. The mobile power system of claim 3 wherein said diode pair comprises a pair of Zener diodes.
5. The mobile power system of claim 3 wherein each of said first switching circuit and said second switching circuit comprises a second switch and a resistor coupled in series; and wherein said second switch and said resistor being coupled in parallel to said first switch.
6. The mobile power system of claim 5 wherein each of said first switching circuit and said second switching circuit comprises a current limiting element coupled between said battery module and said first switch.
7. The mobile power system of claim 1 wherein the load comprises a plurality of loads; and further comprising an AC distribution circuit coupled to said bidirectional AC-DC

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converter and configured to deliver a plurality of AC signals respectively to the plurality of loads.

8. The mobile power system of claim 1 wherein said controller comprises a battery management device configured to monitor a plurality of parameters related to said battery module.

9. The mobile power system of claim 8 wherein the plurality of parameters comprises a total voltage value, voltage values of individual battery cells, a temperature value, a state of charge (SOC) value, a state of health (SOH) value, and a current value.

10. A mobile vehicle platform comprising:

- a vehicle body;
- a plurality of loads carried by said vehicle body; and
- a mobile power system carried by said vehicle body and powering said plurality of loads, said mobile power system comprising
  - a bidirectional alternating current-direct current (AC-DC) converter configured to convert a grid AC signal to a power limited DC charging signal with a threshold level,
  - a battery module configured to provide a DC power signal, and
  - a controller coupled to said battery module and said bidirectional AC-DC converter and configured to selectively switch said bidirectional AC-DC converter between a first state and a second state,
    - the first state comprising, when a load power level is less than the threshold level, concurrently charging said battery module using the power limited DC charging signal and delivering the grid AC signal to said plurality of loads,
    - the second state comprising, when the load power level is greater than the threshold level, concurrently converting the DC power signal with said bidirectional AC-DC converter into a battery AC signal for delivery to said plurality of loads, and delivering the grid AC signal to said plurality of loads.

11. The mobile vehicle platform of claim 10 wherein said controller is configured to selectively switch said bidirectional AC-DC converter between a third state, and a fourth state; wherein the third state comprises, when said battery module is fully charged, and when the load power level is less than the threshold level, delivering the grid AC signal to said plurality of loads and placing said bidirectional AC-DC converter in a stand-by state; and wherein the fourth state comprises when the power limited DC charging signal is unavailable, converting the DC power signal with said bidirectional AC-DC converter into the battery AC signal for delivery to said plurality of loads.

12. The mobile vehicle platform of claim 10 wherein said mobile power system further comprises first and second switching circuits coupled between said battery module and said bidirectional AC-DC converter, each of said first switching circuit and said second switching circuit comprising a first switch, and a diode pair coupled in parallel to said first switch.

13. The mobile vehicle platform of claim 12 wherein said diode pair comprises a pair of Zener diodes each having respective cathode terminals coupled together.

14. The mobile vehicle platform of claim 12 wherein each of said first switching circuit and said second switching circuit comprises a second switch and a resistor coupled in series; and wherein said second switch and said resistor being coupled in parallel to said first switch.

15. The mobile vehicle platform of claim 14 wherein each of said first switching circuit and said second switching



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circuit comprises a current limiting element coupled between said battery module and said first switch.

16. The mobile vehicle platform of claim 10 wherein said mobile power system further comprises an AC distribution circuit coupled to said bidirectional AC-DC converter and configured to deliver a plurality of AC signals respectively to said plurality of loads.

17. The mobile vehicle platform of claim 10 wherein said controller comprises a battery management device configured to monitor a plurality of parameters related to said battery module.

18. A method for making a mobile power system, the method comprising:

coupling a bidirectional alternating current-direct current (AC-DC) converter configured to convert a grid AC signal to a power limited DC charging signal with a threshold level;

coupling a battery module configured to provide a DC power signal;

coupling a controller to the battery module and the bidirectional AC-DC converter and configured to selectively switch the bidirectional AC-DC converter between a first state and a second state; and

coupling at least one switching circuit between the battery module and the bidirectional AC-DC converter, the at least one switching circuit comprising

a first switch, and

a diode pair coupled in parallel to the first switch, each diode of the diode pair having respective cathode terminals coupled together;

the first state comprising, when a load power level is less than the threshold level, concurrently charging the battery module using the power limited DC charging signal and delivering the grid AC signal to a load;

the second state comprising, when the load power level is greater than the threshold level, concurrently converting the DC power signal with the bidirectional AC-DC converter into a battery AC signal for delivery to the load, and delivering the grid AC signal to the load.

19. The method of claim 18 wherein the controller is configured to selectively switch the bidirectional AC-DC converter between a third state, and a fourth state; wherein the third state comprises, when the battery module is fully charged, and when the load power level is less than the threshold level, delivering the grid AC signal to the load and placing the bidirectional AC-DC converter in a stand-by state; and wherein the fourth state comprises when the power limited DC charging signal is unavailable, converting the DC power signal with the bidirectional AC-DC converter into the battery AC signal for delivery to the load.

20. The method of claim 18 wherein the at least one switching circuit comprises first and second switching circuits between the battery module and the bidirectional AC-DC converter, each of the first switching circuit and the second switching circuit comprising a first switch, and a diode pair coupled in parallel to the first switch.

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21. A mobile power system comprising:

a bidirectional alternating current-direct current (AC-DC) converter configured to convert a grid AC signal to a power limited DC charging signal with a threshold level;

a battery module configured to provide a DC power signal;

a controller coupled to said battery module and said bidirectional AC-DC converter and configured to selectively switch said bidirectional AC-DC converter between a first state and a second state; and

at least one switching circuit coupled between said battery module and said bidirectional AC-DC converter and comprising

a first switch,

a diode pair coupled in parallel to said first switch, and a second switch and a resistor coupled in series, said second switch and said resistor being coupled in parallel to said first switch;

the first state comprising, when a load power level is less than the threshold level, concurrently charging said battery module using the power limited DC charging signal and delivering the grid AC signal to a load;

the second state comprising, when the load power level is greater than the threshold level, concurrently converting the DC power signal with said bidirectional AC-DC converter into a battery AC signal for delivery to the load, and delivering the grid AC signal to the load.

22. A method for making a mobile power system, the method comprising:

coupling a bidirectional alternating current-direct current (AC-DC) converter configured to convert a grid AC signal to a power limited DC charging signal with a threshold level;

coupling a battery module configured to provide a DC power signal;

coupling a controller to the battery module and the bidirectional AC-DC converter and configured to selectively switch the bidirectional AC-DC converter between a first state and a second state; and

coupling at least one switching circuit between the battery module and the bidirectional AC-DC converter, the at least one switching circuit comprising

a first switch,

a diode pair coupled in parallel to the first switch, and a second switch and a resistor coupled in series, the second switch and the resistor being coupled in parallel to the first switch;

the first state comprising, when a load power level is less than the threshold level, concurrently charging the battery module using the power limited DC charging signal and delivering the grid AC signal to a load;

the second state comprising, when the load power level is greater than the threshold level, concurrently converting the DC power signal with the bidirectional AC-DC converter into a battery AC signal for delivery to the load, and delivering the grid AC signal to the load.

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